Lawrence Livermore National Laboratory

PROGRAM UPDATE - OCTOBER 2003

Laser Science & Technology

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Brightest 70-keV X-Ray Flux Generated by Thomson Scattering in PLEIADES

The PLEIADES facility (**P**icosecond **L**aser **E**lectron **I**nter**A**ction for **D**ynamic **E**valuation of **S**tructures) is a short-pulse, high-brightness, x-ray source based upon Thomson scattering between an ultrafast, multi-terawatt, Ti:sapphire laser system (called Falcon) and a short-pulse, relativistic electron bunch produced in the s-band, rf linear accelerator (called Linac). Both systems are located in B194. PLEIADES will be used to probe dynamic phenomena in solid materials, such as shock-induced phase changes, equations of state, and molecular motion on time scales ~ 0.1–10 psec. Measuring rapid changes in high-Z materials under stressed conditions has particular relevance to stockpile stewardship.

In an earlier LS&T Program Update (UCRL-TB-136126-03-3, March 2003), we described the activation of the PLEIADES facility and the results of our first x-ray experiments in which we produced ~10^5, 70-keV photons per shot in a ~7-ps x-ray pulse. Since these first results, in partnership with Physics and Advanced Technology (PAT), we have added a new copper cathode to the photo-injector and increased the laser energy at the interaction point to produce a ~20-fold increase in the x-ray flux, making PLEIADES the brightest 70-keV manmade x-ray source in existence.

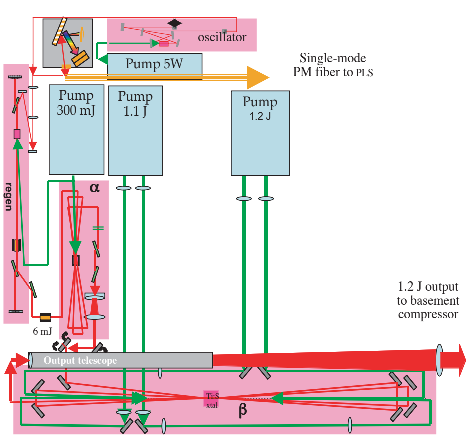

Figure 1. Layout of the Falcon Laser Facility shows the three main Ti:sapphire amplifiers and the output telescope.

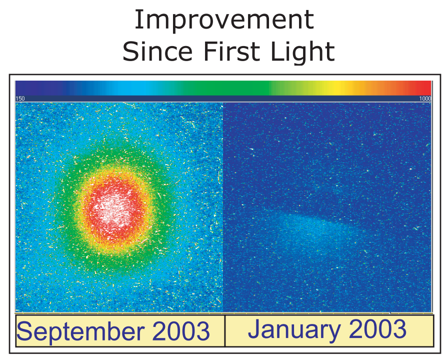

Figure 2. These images show the x-ray spot on a CCD camera and compare the x-ray yield from the initial x-ray measurements (right-hand image) to more recent results after improvements to the laser systems (left-hand image).

Figure 1 shows a layout of the Falcon laser system. The 1.2-J pulse exiting the Falcon laser enters the 70-meter transport system where the beam is relayed using two long telescopes to a large vacuum grating pulse compressor and on to the laser-electron interaction chamber at the output of the Linac. We added a second pump laser (1.1 J Continuum) to the 4-pass-β amplifier to increase the output energy from 0.5 to 1.2 J. We also improved the alignment of the vacuum compressor and removed spectral modulation from the beam to give a measured M^2 value of 1.36 at the interaction point. We added three sets of computer-controlled pointing and centering loops between amplifier stages in Falcon and the Photo-injector Laser System (PLS) to ease alignment and operation during experiments.

These improvements to Falcon have produced a dramatic increase in the x-ray yield. Figure 2 shows the x-ray flux from the Thomson interaction measured with an x-ray CCD camera. The image on the left shows x-ray data taken recently and represents a 20-fold increase in x-ray flux per shot.

Currently, we are measuring the different characteristics of the x-ray source that are important for x-ray diffraction, radiography, and other diagnostics techniques that will be used in pump-probe experiments. One of the important features of the Thomson source is its tunability as described by the equation:

$$h\nu_X = h\nu_L 2\gamma^2 \frac{(1-\cos\phi)}{(1+\gamma^2\theta^2)} \qquad (1)$$

where $h\nu_x$ is the x-ray photon energy, $h\nu_L$ is the laser photon energy, ϕ is the scattering angle (180 degrees) between the laser pulse and photon bunch, θ is the observation angle with respect to the electron trajectory, and γ is the relativistic factor for the electrons. By changing the electron energy, γ, we can tune the x-ray energy.

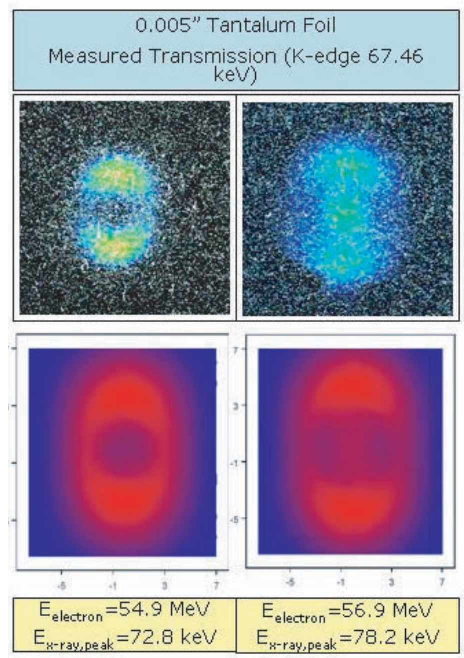

Figure 3. Top: measured transmission through 0.005-inch Ta foil for two electron beam energies; bottom: predicted transmission throughTa foil for the same electron energies.

Figure 3 shows CCD images of x-ray transmission through 250 µm of Ta foil, comparing experiment with theory. By tuning the electron energy to produce x-ray energies just above the K-edge in Ta, we create a hole in the center of the x-ray image from the drop in transmission. If we tune the x-ray energy to higher values, the transmission in the center increases, but drops off for larger values of θ in Eq. (1). By placing an aperture in the x-ray beam to eliminate the higher values of θ, we have a tunable, narrow-line, hard x-ray source of unprecedented brightness for pump-probe experiments in high-Z materials.

—J. Crane, R. Cross, S. Betts, C. Barty, D. Gibson, G. Anderson, S. Anderson, W. Brown, D. Fittinghoff, F. Hartemann, J. Jacobs, J. Kuba, L. James, W. Patterson, P. Springer, A. Tremaine, and V. Tsai

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